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Planting density and sowing date strongly influence growth and lint yield of cotton crops

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A R T I C L E I N F O

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A B S T R A C T

This study assesses the effects of plant population density (PPD) and sowing date (SD) on growth, physiology and lint yield of a cotton crop. Seedling transplanting is one of the most dominant cotton production systems in China. But on the other hand, the net benefit is decreasing because the system is labor intensive. Therefore, a shorter cotton growing season is urgently needed to reduce the production costs through management practices such as adjusting sowing date and PPD. The following hypothesis was tested; would cotton yield and physiology from a late sowing be compensated by plant density? Field experiments were conducted with two sowing dates (S_1, May 20; S_2, June 04) as the main plot and three PPDs (D_1, low; 7.5×10^4; D_2, moderate; 9.0×10^4 and D_3, high; 10.5×10^4 ha^{-1}) as the sub-plot. Early-sown plants produced 23%, 32%, 55%, 77% and 14%, taller stems more nodes, leaves and fruits, respectively, than the late-sown plants. Consequently, S_1 produced 26% higher lint yield than S_2. This increase in lint yield was mainly attributed to a relatively longer cropping season, which allowed utilization of available resources. Growth and fruit production in S1 plants were further increased by an increased photosynthetic rate (*Pn*) and N acquisition. Across the plant densities, 13% and 6% more lint yield was achieved under D_2 than the D_3 and D_1, respectively. Moderate PPD increased lint yield by 13% and 6% over high and low, respectively. Nitrogen (N) acquisition was 45%, 33%, higher for S_1 sown crop compared with S_2, respectively. S_1D_2 had higher average (3.5 V_T kg ha^{-1} d^{-1}) and maximum (4.5 V_M kg ha^{-1} d^{-1}) rates of N accumulation in reproductive organs at the fastest accumulation point among other treatments. Our data suggest that for both sowing dates moderate PPD is a promising option, which allows light interception and penetration to the lower canopy, efficient N utilization and assimilate distribution to reproductive structures.

1. Introduction

Cotton (*Gossypium hirustum* L.) is grown globally as a major source of natural fiber (Constable and Bange, 2015). Due its indeterminate growth habit, the crop shows morphological adaptations to its growing environment such as modification in canopy structure in response to sowing date (SD) and plant population density (PPD) (Mao et al., 2014; Zhang et al., 2003). These morphological adaptations in terms of canopy development, light interception, source sink relationship and assimilates partitioning are the major determinant of lint yield and quality (Yang et al., 2014a,b). Hubei is one of the major cotton growing provinces in China, contributing 12.3% of the total national lint production in less than 9.4% of the planting area (Yang and Zhou, 2010a,b). Despite introduction of high yielding varieties, cotton yield per unit area in this region is stagnant for the last decade (Yang et al., 2014a,b). Cotton planting is a laborious practice in this region due to raised bed sowing and transplantation into open field (Lu et al., 2017). This situation will worsen due to an accelerated migration of farm labor towards cities since1990 (Zhou, 2004). Therefore crop management techniques such as late sowing and high plant population density are often practiced to overcome input costs without sacrificing yield. With the introduction of row planting (Briggs et al., 1967), the concept of

Abbreviation: PPD, plant population density; SD, sowing date; Pn, net photosynthetic rate; AVG, aminoethoxyvinylglycine; FB/FN, fruiting branch to fruiting node ration; RH%, percent relative humidity; FAP, fastest accumulation point; VT, average rate; VM, maximum rate; t_1, t_2 beginning and terminating days of the fast accumulation period; CNP, cotton plant nitrogen VON vegetative organ nitrogen; ROP, reproductive organ nitrogen; DAE, days after emergence

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high density planting system (HDPS) has become popular in the cotton production systems worldwide. However, dense populations (> 10 plants m^{-2}) and subsequent shading may lead to disease infestation, reduced boll size, fruit shedding, delayed maturity and decreased individual plant development (Yang et al., 2014a,b; Bednarz et al., 2006). Current recommended PDD in China was is 22.7 plants m^{-2} in the Northwest (Han et al., 2009), 5.3–7.5 plant m^{-2} in the Yellow River Valley (Dong et al., 2012) and 3.0 plants m^{-2} in the Yangtze River Valley (Yang et al., 2014a,b).

Similar to PPD planting time is an important determinant of lint yield and quality in cotton farming systems. Timely planting of crops is essential for root penetration and proliferation, and vegetative growth for optimum harvesting of available soil nutrients and solar radiation (Soler et al., 2007). Early planted crops may experience some challenges of seedling establishment due to low temperatures and high insect pest incidence (Pettigrew and Adamezyk, 2008). Late planting, in contrast, usually reduces cotton yield due to delayed physiological maturity and carbohydrate deficiency (Gwathmey and Clement, 2010). Both PPD and planting time strongly influence N status in cotton leaves, which is positively associated with canopy photosynthetic capacity (Poorrter and Evand, 1998). Synchronization of crop N demands with its supply is crucial for improving crop nitrogen use efficiency (NUE). N demand for a crop is strongly related to yield potential, which in turn is associated with N supply and crop management (Yousaf et al., 2016). Since nutrient uptake and PPD are strongly associated, increasing plant density may lead to an increased N uptake in reproductive tissues. High plant population favors high N uptake and N translocation from vegetative structures to reproductive organs (Jiang et al., 2013).

A leaf with a history of low light has lower photosynthetic saturation relative to an illuminated leaf, and this is particularly important when the cotton crop is grown under dense PPD (Landivar et al., 2010). The affinity of the enzymes involved in carbon fixation e.g., rubisco increases under low light conditions (Jenson, 1986), which imbalances ethylene/sugar ratio and can lead to abscission of the reproductive structures (Zhao and Oosterhuis, 2000). The rubisco has high affinity with O_2 and CO_2 (Jenson, 1986), and photorespiration is increased under low light conditions. This increased ethylene/sugar ratio can lead to abscission of reproductive structures (Guinn, 1974), and cotton yield reduction (Zhao and Oosterhuis, 2000). Thus, time of sowing and plant density can be an important determinant of growth cycle of a cotton crop phenology, growth and development. However, limited information is available on their combined effects on nutrient dynamics, growth, leaf photosynthetic capacity and lint yield of cotton crop. This study explores, the role of plant density and sowing date on (1) cotton growth, lint yield, leaf photosynthetic capacity and nutrient dynamics at different phenological stages; and (2) elucidates the quantitative relationship between planting density and planting date. These data will provide crop management guidelines to cotton growers.

2. Materials and methods

2.1. Experimental site and cultivar

Field studies were conducted in 2014 and 2015 on the experimental farm of Huazhong Agricultural University, Wuhan, China (30° 37′ N latitude, 114° 21′ E longitude, 23 m above sea level). Soil of the experimental site was yellowish brown and clay loam comprising of 1.2% organic matter, 81.7 mg kg^{-1} alkaline N, 21.3 mg kg^{-1} P_2O_5, and 78.4 mg kg^{-1} K_2O. Mean air temperature was higher during seedling establishment, vegetative growth and remained relatively lower during reproductive periods of both years. On average, 2014 was relatively cooler than 2015. Relative humidity was associated with air temperatures during earlier crop stages. It was low during early growth phases and increased as canopy gets closer (Table 1). A cotton cultivar Huazamian H318 (*G. hirsutum* L.) having moderate maturity was used for the present study.

Table 1
Description of climatic parameters during 2014 and 2015.

Month	2014				2015			
	Max°C	Min°C	Mean°C	RH%	Max°C	Min°C	Mean°C	RH%
May	26.8	17.1	22.0	80.6	27.0	18.4	22.7	82.4
June	30.1	21.4	26.0	65.7	31.2	22.5	26.9	68.7
July	41.0	26.5	34.0	62.2	43.3	28.1	31.2	63.1
August	40.2	23.4	31.8	69.1	41.5	24.6	33.1	70.0
September	31.5	21.1	26.3	75.5	33.4	22.7	28.1	75.6
October	28.4	15.3	21.9	70.3	29.3	17.2	23.3	71.2
Average	33.0	20.8	27.0	70.5	34.3	22.3	28.0	71.8

2.2. Experimental design, treatment and crop management

The experiment was conducted in a split-plot arrangement e.g. three plant densities (D_1, low; 7.5 × 10^4; D_2, moderate; 9.0 × 10^4 and D_3, high; 10.5 × 10^4 ha^{-1}) randomly assigned (sub plot) with two planting dates (S1, early May 20; S2, late June 04) (main plot). The split-plot arrangement with four independent replicates was used to increase the precision of comparisons. The experimental sub plot was size consisted of a 12 m long and 3.04 m wide with total plot size of 36.48 m^2. Row spacing of the experimental treatment consisted of narrow row spacing (25 cm) and wide row spacing (76 cm). Plant spacing was adjusted according to the corresponding plant population density. Each sub plot was consisted of four rows with narrow row and wide row space. Cotton seeds were sown on raised bed by hand in respective plots. Seedlings were thinned two weeks after emergence to the required plant density (75,000, 90,000 and 105,000 ha^{-1}). Fertilizer, at the rate (kg ha^{-1}) of 180 N, 54 P_2O5, 180 K_2O, 1.5 B with urea (46% N), superphosphate (12% P_2O_5), potassium chloride (59% K_2O) and borate (10% B), were applied at early flowering (66 days after emergence). Cultural management practices such as irrigation, weeding, hoeing and pesticide application were implemented to reduce competition for nutrient, light, water and spacing for a better crop stand. Mepiquat chloride was applied as a growth regulator in order to speed up boll opening and reduce excessive vegetative growth.

2.3. Observations

2.3.1. Cotton plant growth characteristics

At peak boll stage (74 days after emergence), fifteen plants per plot were randomly selected to measure plant height using a specially designed ruler. Cotton fruiting branch length was measured from the point of attachment to the end of the branch. Number of fruiting branches nodes and leaves were counted from fifteen randomly selected plants in each plot. Fruiting branch length data were divided by fruiting branch number to obtain fruiting branch length to fruiting branch numbers ratio (FB/FN).

2.3.2. Yield and yield contributors

Seed cotton yield (fiber and seed) was recorded three times from the manually harvested plants in each sub plot. The boll was sun dried to ≤ 11% water content (Dong et al., 2010), and ginned to obtain lint yield. Prior to second harvest one hundred fully matured open bolls were picked from each plot dried and ginned to calculate individual boll weight and lint%. Individual boll weight was calculated by total seed cotton yield of 100 bolls divided by total boll number. Lint% was assessed from the ratio of lint yield derived from 100 bolls divided by seed cotton weight of 100 bolls.

2.3.3. Net photosynthetic rate (Pn)

Net photosynthetic rate (Pn) was measured at various reproductive growth stages e.g. squaring (47 days after emergence) (DAE), first bloom (66 DAE), peak bloom (74 DAE) and boll opening (121 DAE)